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Technical Memorandum

SUMMARY OF HELICOPTER AIRFRAME TESTING IN THE SHIPBOARD ENVIRONMENT

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This paper presents a summary of test results from several helicopter shipboard test programs. Data are presented from the HH-2D test on the FF-1052 class USS W.S. SIMS in 1970, the SH-2F on the FF-1052 class USS BOWEN in 1974, and the HH-3F on the WHEC class USCG HAMILTON in 1975. Improvements in NATOPS manual information are highlighted in the areas of wind and/or airspeed limitations, cockpit indications, and helicopter performance information for both level flight and climb and descent. Shipboard deck strength and landing gear capabilities are addressed and a statistical data base is presented from which extrapolations to the "sea state 5" environment may be made.

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PREFACE

This paper was prepared for presentation 11 May 1977 at the 33rd Annual National Forum of the American Helicopter Society held in Washington, D.C. Information contained herein is extracted from various NAVAIRTESTCEN 'Dynamic Interface" test programs conducted to establish shipboard launch/land flight restrictions aboard Aviation Facility (Destroyer-type) Ships. Source information is appropriately referenced. This paper, along with reference 3, are valid input documents to the NAVTOLAND Program under AIRTASK A03P-03PA/053B/7WF21-211-000.

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Summary of Helicopter Airframe Testing
in the Shipboard Environment

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Abstract

This paper presents a summary of test results from several helicopter shipboard test programs. Data are presented from the HH-2D test on the FF-1052 class USS W.S. SIMS in 1970, the SH-2F on the FF-1052 class USS BOWEN in 1974, and the HH-3F on the WHEC class USCG HAMILTON in 1975. Improvements in NATOPS manual information are highlighted in the areas of wind and/or airspeed limitations, cockpit indications, and helicopter performance information for both level flight and climb and descent. Shipboard deck strength and landing gear capabilities are addressed and a statistical data base is presented from which extrapolations to the "sea state 5" environment may be made.

Introduction

The NAVAIRTESTCEN has been developing safe launch and recovery envelopes for helicopter operations aboard ship since 1970. During that period, 27 such dynamic interface tests have been completed, but only 4 involved fully instrumented helicopters and ships. Of those four, limits of ship motion and wind-over-deck have been achieved only once -- aboard USS BOWEN FF-1052 class in January 1974.

The planning and logistics problems associated with successful at-sea tests are complex. Not only is an instrumented test helicopter and ship deck required, but the required sea state may not be available. The USS BOWEN tests had all of the success ingredients available; in fact, the sea state increased from 1 to 5 in proper sequence to allow a gradual buildup to the critical end points of ship motion. Results of these tests are presented in references 1 and 2, and a paper was presented to the American Society of Naval Engineers (ASNE) in May 1975, reference 3.

Additional tests have been completed during the past 3 years: the SH-2F/USS SPRUANCE (DD-963), the SH-2F/SSP KAIMALINO, the HH-3F/USCG HAMILTON (WHEC-715), the SH-3D/USS CHICAGO (CG-11), and the YSH-3J/USS MOUNT BAKER (AE-23 class). Results are reported in references 4 through 8, respectively. The YUH-60A and YUH-61A Army UTTAS contenders were evaluated aboard the USS PAUL (FF-1080) in June 1975 and results appear in reference 9.

The USS BOWEN and USCG HAMILTON tests have produced the most complete set of data ever assembled in the helicopter/ship dynamic interface environment. These data form the basis of this paper and will also be used as a baseline for future tests, specifications, and flight envelope definitions. The at-sea tests also showed the need for improved cockpit displays and more complete handbook information.

Operational Flight Envelopes

Flight handbooks do not always contain the most useful operational information; either the data are not available or they may be presented in poor format. Operational flight envelopes are a prime example. Figure 1 shows the flight limits information extracted from the UH-1N NATOPS Flight Manual, reference 10, in a lateral and longitudinal velocity axis system. Note that relative wind limits in all quadrants except on the aircraft axes are undefined, or at minimum, subject to interpretation by the operators. Helicopter operations are obviously not constrained only to the aircraft axes (i.e., forward, rearward, left sideward, and right sideward); therefore, the operator should be given a definitive limitation around the azimuth.

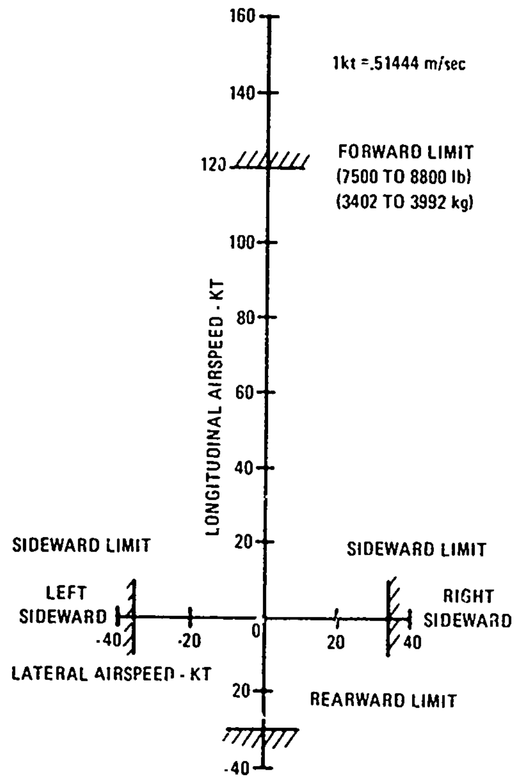

Figure 1
UH-1N Airspeed Limits

Sideslip limits in forward flight are addressed as shown in figure 2, again for the UH-1N helicopter. The limitations are presented in terms of sideslip angle, a parameter for which instrumentation is provided in test and evaluation helicopters, but is not available to the fleet pilot.

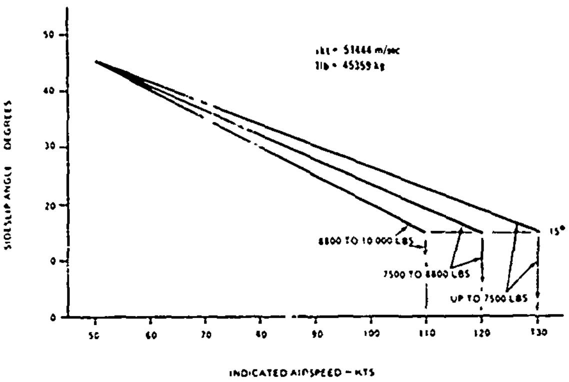

Figure 2
UH-1N Sideslip Limitations

In figure 3, the sideslip limit has been converted to lateral and longitudinal velocity components and is shown hatched along the previously defined limits of the operational flight envelope in NATOPS. Presumably, the V_{max} limit applies out to the 15 deg sideslip limit intersection. This figure shows some interesting results for the UH-1N. While the left lateral velocity limit in "hover" is 30 kt (15.4 m/s), a 49 kt (25.2 m/s) left lateral component can be accepted at 80 kt (41.2 m/s) forward airspeed within the sideslip limitation. On this same figure, the additions required to define the flight envelope around the azimuth are shown. This envelope limitation diagram will be expanded later in this paper.

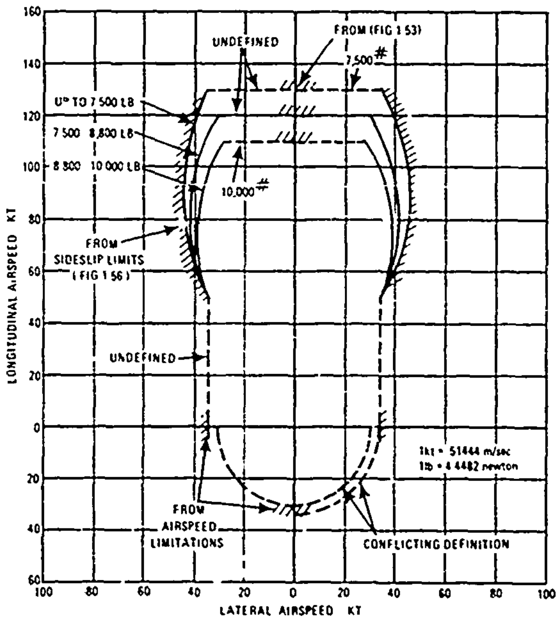

Figure 3
Complete Airspeed Limitation

These are examples of flight limitations which are not clearly defined in the handbooks. The problem is compounded when parameters, such as sideslip angle and lateral velocity, are used to define envelopes, yet the pilot's instrument panel does not contain these displays. Current helicopter airspeed indicators allow the pilot to monitor longitudinal airspeed from approximately 40 kt (20.6 m/s) to V_{max}. As previously mentioned, there are no sideslip indicators in fleet helicopters, and currently installed airspeed indicators are notably unreliable below 40 kt (20.6 m/s). In addition, there are no omnidirectional low airspeed indicators in the fleet, though several are currently being tested. A reliable low airspeed indicating system with lateral velocity readout would enhance shipboard operations and allow the pilot to remain within the flight envelope. This would permit the pilot to utilize the maximum capabilities from the helicopter in the hover and low airspeed flight regimes, promoting safety and efficiency.

Helicopter Performance

Testing of the USCG HAMILTON with the HH-3F and on the USS MOUNT BAKER with the YSH-3J at high gross weights has pointed out the need to more adequately define the minimum Wind-Over-Deck (WOD) performance requirements to launch a heavy helicopter from the ship. Flight envelope limits are typically based on the indication of wind from the bridge anemometer (hopefully operating properly) and include sufficient margins for: (1) varying pilot techniques, (2) wave-off/takeoff power transients, (3) turbulence, and (4) unknowns in weight variation. Limits are established in a buildup program in weight and indicated relative wind. The classical power required curve, as shown in figure 4 for the H-2, does not define the total spectrum of performance for two very important reasons: (1) basic testing of the airframe has generally been inadequate to define the performance of the helicopter between hover and approximately 40 kt (20.6 m/s) and (2) performance testing is oriented along the centerline axis of the helicopter. The ball-centered versus zero-sideslip testing philosophies are duly acknowledged; however, what is really needed is a whole new concept of visualizing and conducting helicopter performance testing.

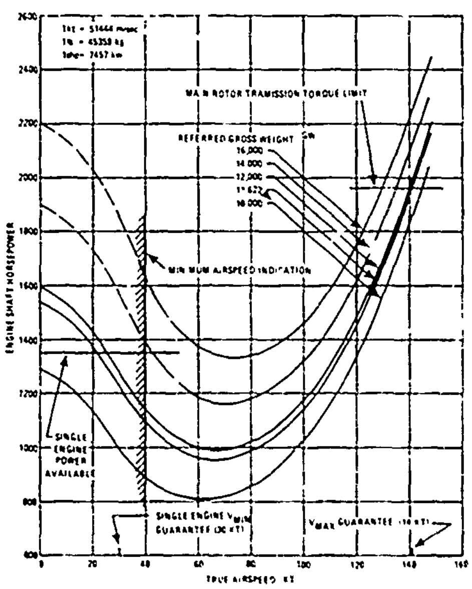

Figure 4
H-2 101 Rotor System Dimensional Performance

The suggested three-dimensional format would start with the format of figure 3 in X and Y coordinates as the base and define power up the vertical (or Z) axis; the flight limits now become limitation surfaces. A power required surface can be defined which will take the form of figure 5, assuming level flight conditions. This figure is admittedly conceptual except along the longitudinal axis above zero, where it takes the form of classical helicopter performance. The classical power required curve of figure 4 can been seen by looking in along the X axis at the Y-Z plane. Test programs should be designed to systematically define this helicopter performance surface in order to fully define the flexibility of the helicopter. An immediate use might be the data base for helicopter simulators, as discussed in a separate NAVAIRTESTCEN paper, AHS 77.3-62. Another use might be the resolution of the ball-centered versus zero-sideslip discussion, since both areas are covered on this format. A third use might be the complete definition of helicopter performance as a baseline for a shipboard wind turbulence survey, using an instrumented helicopter and parameter identification techniques. Such a performance mapping program would define the low airspeed capabilities of the helicopter, along with appropriate flight envelope limits and the forward flight sideslip limits. Pilots would then be aware of the helicopter's true performance limitations.

Low/Lateral Airspeed Indication

Even though a complete performance map has now been developed, as noted above, the pilot still has no way of determining where he is operating on the surface. The need for a low/omnidirectional airspeed indicating system for the fleet pilot becomes obvious. An accurate and reliable airspeed system is required for safe and effective operation in that portion of the flight envelope which makes the helicopter versatile and unique. If full utilization of the helicopter is to be achieved for its capabilities, the pilot needs an understanding of his aircraft's capabilities and limitations and a reliable system to tell him where he is with respect to those limitations. Accidents will hopefully be reduced because the pilot knows his true limits and can keep himself within them.

Climb/Descent Performance

Climb/descent performance information contained in the pilots' operating manuals is insufficient to present a thorough understanding of his situation and options. Figure 6 shows a very useful climb/descent performance chart which has been defined for the BO-105 helicopter (reference 11). This one figure defines for the pilot the following information at one gross weight: V_H; V_{NE}; V_{NE}(auto); best climb airspeed; minimum autorotation airspeed; V_{max} 1-engine; V_{min} 1-engine; angle of climb and variation with airspeed; angle of descent and variation with airspeed; Vortex ring state and how to avoid it; maximum single engine climb speed and rate of climb; IFR approach envelope; and landing sink rate capability. A chart similar to figure 6 should be defined for each helicopter in the fleet inventory and included in the NATOPS Manual.

Ship Deck and Landing Gear Strength Requirements

In the early days of LAMPS, the Navy felt that the shipboard helicopter landing pads on DE-1040 and DE-1052 (now FF-1040 and FF-1052) class ships, originally designed for the QH-50 drone helicopter, would have insufficient strength for the much heavier H-2. A test program was conducted on the USS W.S. SIMS (references 12 and 13) to test the deck strength for helicopter landings by the HH-2D. This test was a "small deck" DE-1052 configuration with the original H-2 landing gear configuration (aft tail wheel and 8 ft/sec (2.4 m/s) capable gear). Since that test, the DE-1052 decks have been enlarged, and the SH-2F landing gear has been modified by relocating the tail wheel 6 ft (1.8 m) farther forward and increasing the maximum landing gear sink rate capability from 8 ft/sec (2.4 m/s) to 12 ft/sec (3.7 m/s). In addition, two UTTAS prototypes were tested in June 1976 at 15,400 lb (6 989 kg) aboard the USS PAUL (FF-1080).

Surprisingly, the most severe environment for the ship deck structure was the USS W.S. SIMS test of the lighter, lower sink rate capability HH-2D. This was contrary to intuition, which held that deck loads would increase as both gross weight and sink rate increased. Reference to figure 7 will reveal that the SH-2F, with increased landing gear capability to 12 ft/sec (3.7 m/s), was able to reduce landing loads. Dynamic landing loads were attenuated by increasing the stroke of the SH-2F landing gear struts; the CG normal load factor spike of the SH-2F with the new landing gear at 12 ft/sec (3.7 m/s) was actually less than the normal load factor spike of the original landing gear at 8 ft/sec (2.4 m/s).

Figure 8 presents deck load data for the two H-2 gear configurations, along with a preliminary analysis of the deck reaction load of one of the UTTAS vehicles (reference 14). It can be seen that at sink rates above 4 ft/sec (1.2 m/s), the UTTAS at 15,400 lb (6 989 kg) demonstrated less deck load or deck pressure than either H-2 configuration. If deck pressure is the shipboard deck limitation, the UTTAS airframe will be compatible with current decks. The large, 75 psi (517 kPa) UTTAS tires spread the landing load over a much larger area than do the smaller 250 psi (1 724 kPa) SH-2F tires, which is a prime contribution to this decreased deck pressure loading. More detailed analyses of helicopter shipboard landing loads are needed. The corollary is to determine which of the two parameters, deck load or deck pressure, is the more critical shipboard limitation.

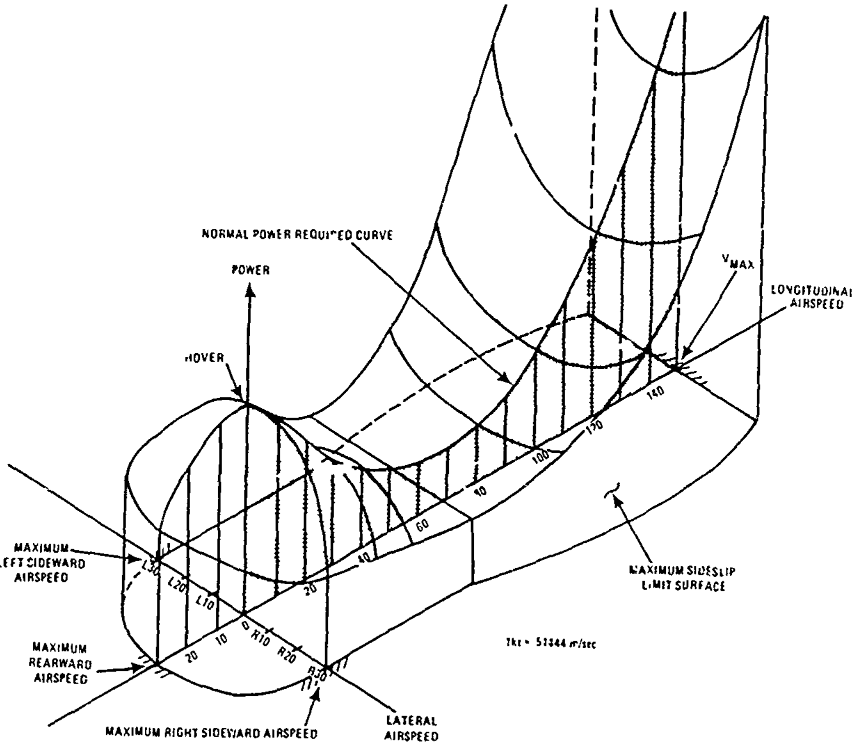

Figure 5
Three-Dimensional Helicopter Performance

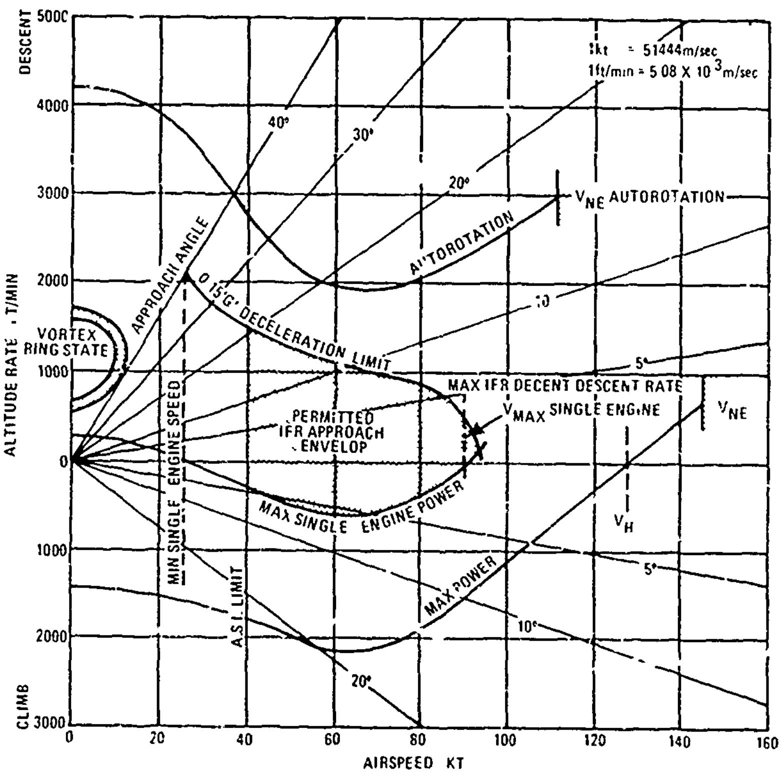

Figure 6
Typical IFR Flight Envelope - BO-105

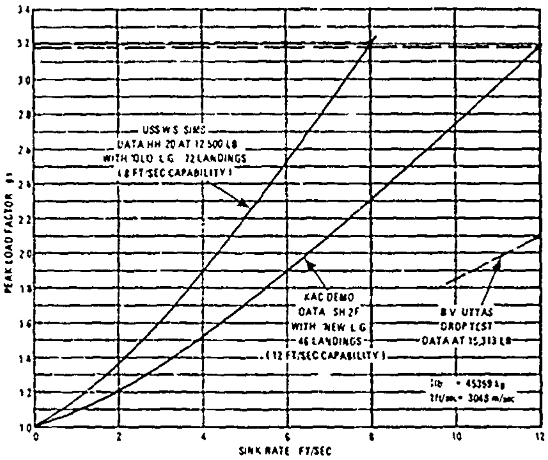

Figure 7
SH-2F Gear Modifications
and UTTAS Comparison

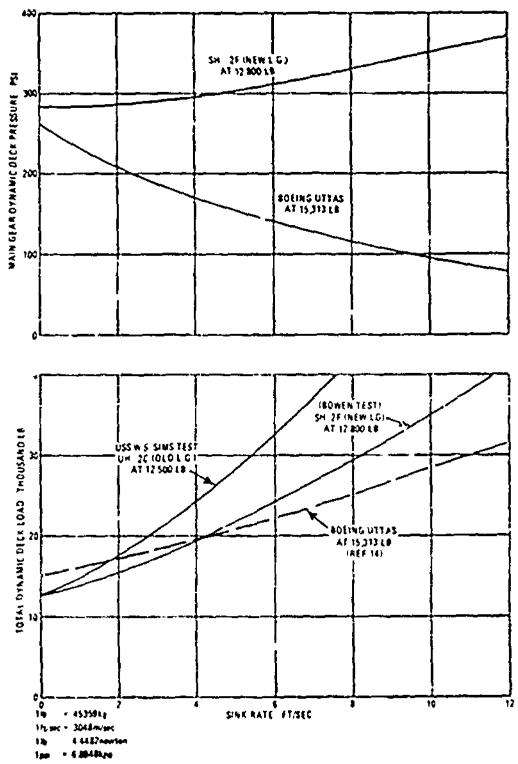

Figure 8
Deck Loads and Pressures

Shipboard Landing Environment

Many attempts have been made to deter...ine the "sea state 5" limits for the shipboard landing environment. Sea state 5 is a very nebulous term and ranges from 8 to 13 ft (2.4 to 4 m) "significant wave height." Significant wave height is a statistical term defined as the average of one-third of the highest wav-s encountered. An attempt was m.ade during the USCG HAMILTON trials to apply a statistical analysis to the landing environment data from a deck-mounted camera. Several of the landing parameters in a given test period were statistically analyzed to estimate their mean and standard deviation. From this analysis, the relative helicopter sink rate versus the measured significant wave height was developed as presented in figure 9. This represents significant wave height (a statistic) plotted against the mean of a series of landings (also a statistic). This was done in an attempt to extrapolate landing data beyond the conditions encountered in the test, and at the same time, to establish some minimum level of confidence regarding that extrapolation. For the purpose of this statistical model, the sink rate data were assumed to be from a normal (gaussian) distribution.

This same format was used for five other landing parameters, including relative lateral and longitudinal velocities, relative pitch and roll rates, and relative pitch and roll angles. For example, figure 10 shows the tendency of the pilot to land when the deck is level (as stated in reference 3). The other plots are contained in the USCG HAMILTON report (reference 6). Table I summarizes essential characteristics of the extrapolated data for upper sea state 5 for the Coast Guard HH-3F on the USCG HAMILTON class (WHEC) ship. This information could be used as a conservative definition for the landing gear requirements for the next generation of shipboard helicopters. The logic of a conservative definition arises because of the fact that the statistical USCG HAMILTON data base did not yield the lull or quiescent period characteristic. Pilots will modify their landing technique when the maximum motion is encountered as indicated by the USS BOWEN data on figure 9.

Table I

Extrapolations to Top of Sea State 5
SWH = 13 ft (4 m)

Parameter	Mean $\bar{X}$	Std. Dev. S_x (σ)	1-100 Max. ($\bar{X} \pm 3\sigma$)
$\dot{Z}_{LMG.}$ (ft/sec)/(m/sec)	7.4/2.26	1 02/.31	10 5/3 20
$\dot{Z}_{RMG.}$ (ft/sec)/(m/sec)	9.1/2.77	1.24/ 38	12.8/3.90
$\dot{Z}_{NOSE}$ (ft/sec)/(m/sec)	9.5/2.90	1.06/.32	12.7/3.87
Roll Angle (deg)	-3	2.51	-10 53
Roll Rate (deg/sec)	12	5 6	26 8
Pitch Angle (deg)	2	1.1	5.3
$\dot{X}$ (ft/sec)/(m/sec)	3.2/.97	1.24/.38	6.92/2.0

Figure 11 presents histograms of sink rate for several important test programs. The data were acquired from structural test programs, from the USS BOWEN sea state 5 tests, and from the Coast Guard HH-3F tests aboard the USCG HAMILTON, with and without the deck grid installed. High sink rates (above 6 ft/sec (1.8 m/s)) were measured only during the structural test programs, where test pilots were deliberately aiming for end points. The second series of USCG HAMILTON tests showed extremely low sink rates, resulting from both increased pilot proficiency and the removal of the deck grid. The 12 ft/sec (3.7 m/s) Navy demonstration requirement appears to be operationally sound, since even the most critical USS BOWEN sea state 5 landings never exceeded 8 ft/sec (2.4 m/s).

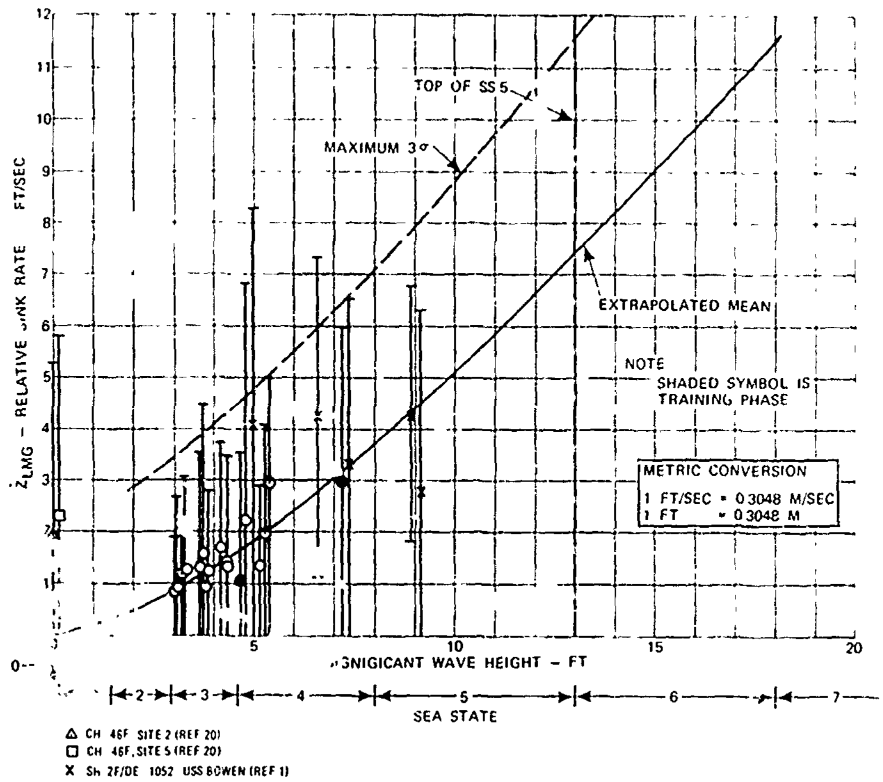

Figure 9
Left Main Gear Sink Rate Extrapolation

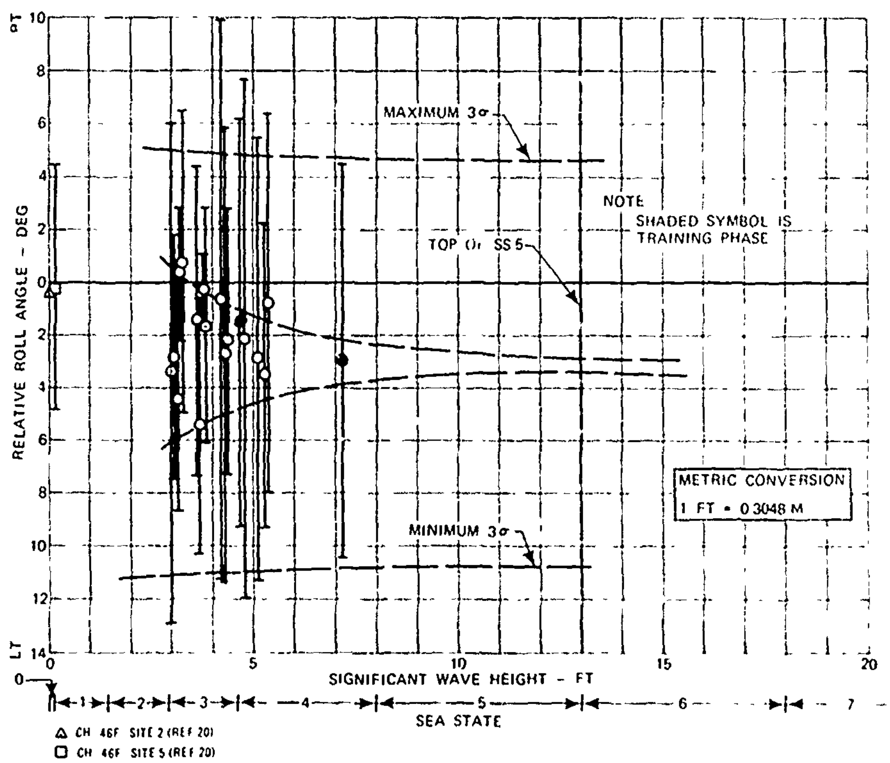

Figure 10
Roll Angle Extrapolation

1 TEST SHIPBOARD USS W. S SIMS, HH-2D ON FF 1052 CLASS (REF. (12))
PILOTS TASK· "BUILD UP TO BUT DO NOT EXCEED 8 FT/SEC SINK RATE, HIT ON 1 FT SQ. TARGET."
MEAN SINK RATE=4.762, σ=1 82, PROBABILITY OF EXCEEDING 8 FT/SEC = 3 6%, N = 80.

2 TEST· SHIPBOARD USS BOWEN, SH-2F ON FF 1052 CLASS (REF (1)).
PILOTS TASK "NORMAL SHIPBOARD LANDING."
MEAN SINK RATE = 3.9, σ = 1.28, PROBABILITY OF EXCEEDING 8 FT/SEC = 0.1%, N = 72.

3 TEST SHIPBOARD USCG HAMILTON, HH-3F ON WHEC CLASS (REF (6)).
PILOTS TASK· "TRAINING" - LANDING INTO GRID
MEAN SINK RATE = 2 37, σ = 1 11, PROBABILITY OF EXCEEDING 6 FT/SEC = 0%, N = 28

4 TEST SHIPBOARD USCG HAMILTON, HH-3F ON WHEC CLASS (REF (6))
PILOTS TASK· "NORMAL SHIPBOARD LANDING INTO GRID"
MEAN SINK RATE = 1 68, σ = 91, PROBABILITY OF EXCEEDING 6 FT/SEC = 0%, N = 87.

5 TEST SHIPBOARD USCG HAMILTON, HH 3F ON WHEC CLASS (REF. (6)).
PILOTS TASK 'TRAINING' - NO GRID
MEAN SINK RATE = 1 06, σ = 79 PROBABILITY OF EXCEEDING 6 FT/SEC = 0%, N = 26

6 TEST SHIPBOARD USCG HAMILTON, HH 3F ON WHEC CLASS (REF (6))
PILOTS TASK NORMAL SHIPBOARD LANDING' - NO GRID
MEAN SINK RATE = 1 22, σ = 62, PROBABILITY OF EXCEEDING 6 FT/SEC = 0%, N = 54

7 TEST SH-2F MODIFIED LANDING GEAR DEMONSTRATION
PILOTS TASK DEMONSTRATE LEVEL, SLOPED AND DRIFTED LANDINGS (KAC DATA).'
MEAN SINK RATE = 5 92, σ = 2 37 PROBABILITY OF EXCEEDING 12 FT/SEC = 0 5% N = 46

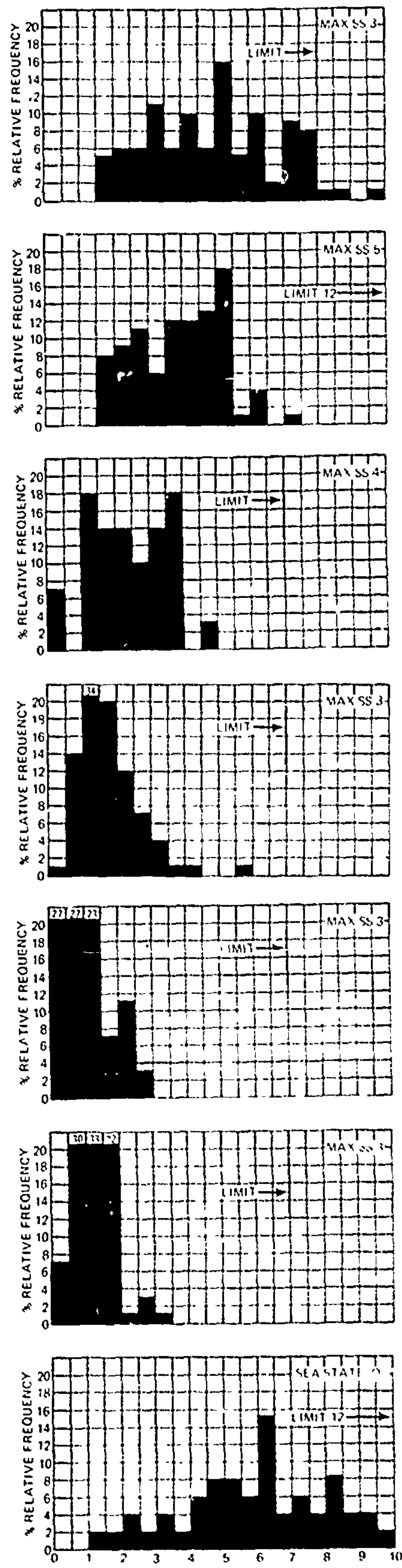

Figure 11
Sink Speed Environment

Additional Technology Areas

Several important shipboard environment technology references are listed without further comment. These include a state-of-the-art paper on ship motion, reference 15; the most recent and concise description of the "dynamic tipover" phenomenon, reference 16; and a theoretical analysis thereof, reference 17; an analysis of the high-speed effects of a Surface Effect Ship (SES) on helicopter operations, reference 18; and finally, a wind tunnel analysis of the ship air wake, reference 19.

Conclusions

NAVAIRTESTCEN at-sea dynamic interface tests aboard the USS BOWEN and USCG HAMILTON produced invaluable data which will serve as a baseline for future tests, specifications, and flight envelope development. At-sea test programs have also shown the need for improved cockpit displays, improved sensors, more complete handbook information, and innovative performance presentations. Increased sink rate and gross weight capabilities do not necessarily increase deck loads and pressures. The statistical analysis of landing data at lower sea states allows extrapolation to upper sea state 5 recovery envelopes.

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NAVAIR (PMA-266)	(1)
NAVAIR (PMA-269)	(1)
DTNSRDC (Code 1568)	(2)
DTNSRDC (Code 1660)	(1)
DTNSRDC (Code 17)	(1)
NAVSEASYSCOM (PMS 389)	(2)
NAVSEC (NSEC 6162C)	(2)
ASNE	(2)
CNO (OP-321E)	(2)
Office of Research and Development (G-D/TP53)	(1)
Office of Engineering (G-E/64)	(1)
Office of Operations (G-O/73)	(1)
DDC	(12)
NAVAIRTESTCEN (CT-02)	(1)
NAVAIRTESTCEN (CT-84)	(1)
NAVAIRTESTCEN (CT-08)	(1)
NAVAIRTESTCEN (SA-01)	(1)
NAVAIRTESTCEN (SY-01)	(1)
NAVAIRTESTCEN (AT-01)	(1)
NAVAIRTESTCEN (TP-01)	(1)
NAVAIRTESTCEN (RW-01)	(15)
NAVAIRTESTCEN (CS-01)	(1)